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Bio-efficacy and phyto-toxicity of post-emergence herbicides tank mixtures on soybean (*Glycine max* L. Merrill)

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Abstract
The field experiment was replicated thrice in randomised complete block design at Main Agricutural Research Station, Dharwad during *kharif* 2018 to study the bio-effiacy and phyto-toxicity of post-emergence herbicides tank mixtures on soybean (*Glycine max* L. Merrill). Application of Imazethapyr 75 g ha^{-1} + Quizalofop-p-ethyl 37.50 g ha^{-1} (75% RD) recorded significantly lower weed density (6.67 and 8.67 m^{-2} at 40 and 60 DAS, respectively), total weed dry weight (1.90 and 2.73 g m^{-2} at 40 and 60 DAS, respectively), and weed index (11.98%) with significantly higher weed control efficiency (77.75 and 85.79% at 40 and 60 DAS, respectively) seed yield and net returns (2,554 kg ha^{-1}, ₹ 59,111 ha^{-1}, respectively) over Imazethapyr alone. It was at par with RWMP (2,652 kg ha^{-1}, ₹ 62,111 ha^{-1}, respectively) and Imazethapyr 75 g ha^{-1} + Propaquizafop ethyl 75 g ha^{-1} (2,356 kg ha^{-1}, ₹ 50,791 ha^{-1}, respectively). There was.broad spectrum weed control through herbicide tank mixtures compared to Imazethapyr alone. Phytotoxicity was not observed due to tank mixtures of herbicides.

Keywords: Soybean, imazethapyr, weed control efficiency and weed index

Introduction
Soybean (*Glycine max* L. Merill) is an important oil seed crop of India with high protein (40-42%) and oil (20-22%). Being nitrogen fixing crop, it provides good returns to farmers even with low level of farm inputs. Soybean is very sensitive to early weed infestation. The critical crop weed competition period in soybean was observed at 27 to 40 days after sowing (Chhonkar and Balyan, 1999) [1]. The uncontrolled weeds at critical period of crop weed competition will reduce the yield of soybean by 58 to 85 per cent depending upon type and intensity of weed infestation (Singh and Singh, 1987) [7]. Hand weeding, hoeing is a common practice of weed control in soybean, however, non-availability of labour or continuous rains often prevents timely weed control by such practices. Under such situations, application of herbicides offers an alternate and equally effective method of weed control. Post-emergence herbicides provide the farmers to have a wide choice of application time from 10-30 days after sowing. Several herbicides *viz.*, Pendimethalin, Fluchloralin, Metalochor and Alachlor etc. were in use for controlling weeds associated in soybean, but these have not been found much effective in controlling all types of weeds. Henceforth, it is imperative to evaluate the efficacy of suitable post-emergence herbicide mixtures for effective control of dominant and diversified weed flora in soybean fields. Imazethapyr is the presently recommended post emergent herbicide which does not control all type of weeds especially grasses. Hence, there is need to mix it with other herbicides which are effective against grasses to achieve broad spectrum weed control. Keeping these points in view, effect of post emergent herbicide tank mixtures on weed control in soybean was studied.

Material and Methods
The field experiment was conducted at Main Agricultural Research Station, Dharwad, which is situated at 15^0 29^1 North latitude, of 74^0 59^1 East longitude and at an altitude of 689 meters above mean sea level, located in the Northern Transition Zone (Zone -8) of Karnataka, during *kharif* 2018. The experiment consists of 14 treatments (Table 1) with 3 replications and was laid out in randomized complete block design with plot size of 6.0 m x 3.6 m. The soil of the experimental field was black clayey type with medium available nitrogen (283 kg ha^{-1}), medium available phosphorus (30 kg ha^{-1}), medium available potassium (340 kg ha^{-1}), organic carbon (0.52%) with pH of 7.3 and EC (0.24 dS m^{-1}). The soybean (DSb-21) seeds were dibbled @ 62.5 kg ha^{-1} with a spacing of 30 cm x 10 cm. Recommended fertilizer dose of 40: 80: 25 kg NPK ha^{-1} was applied through urea, DAP and MOP at the time of sowing.

The spray volume used for pre-emergent herbicide i. e pendimethalin was 750 litres per ha and for post emergent herbicides 500 litres per ha. The post emergent herbicides tank mixtres were uniformly applied at 23 DAS. The observations were taken in randomly selected and tagged five plants in each plot. Crop was harvested at maturity, threshed plot-wise and grain yield and haulm yield in kg ha^{-1} was recorded. Total weed population m^{-2} and total weed dry matter was recorded at 40 DAS and 60 DAS under each treatment with the help of 0.25 m^{-2} quadrat. Data on weed density and weed biomass were transformed using square root transformation. Weed control efficiency and weed index were computed using following formula.

$$WCE\ (\%) = \frac{X - Y}{X} \times 100$$

Where, WCE = Weed Control Efficiency, expressed in percentage, X = Total weed dry weight in unweeded control plot, Y = Total weed dry weight in the treated plot

$$WI\ (\%) = \frac{X - Y}{X} \times 100$$

Where, WI = Weed Index expressed in percentage, X = Yield of weed free plot, Y = Yield from treatment for which weed index is to be worked out.

Results and Discussion

The perdominant weed flora observed in the experimental field consisted of grassy weeds *viz*, *Cynodon dactylon* L., *Brachiaria eruciformis*, *Dinebra rectroflexa.* Among broad leaf weeds (BLWs), *Mollogo disticha*, *Digera arvensis*., *Phyllanthus maderaspatensis* L., *Corchorus trilocularis*, *Portulaca oleracea* L., *Knoxia mollis*, *Commelina benghalensis* L., *Euphorbia geniculata*, *Alternanthera sessilis* L., *Convovulus arvensis* L., *Conyza ambigua* and *Leucas aspera* were dominant. Among sedges, *Cyperus rotundus* was noticed. Similar weed spectrum was noticed by Prachand *et al*. (2014) [5], Manjunath and Hosmath (2016) [4].

Effect on weed parameters of soybean

At 40 and 60 DAS, RWMP (Pendimethalin 1 kg ha^{-1} PE + one intercultivation at 20-25 DAS) recorded lower weed density (2.33 and 4.00 m^{-2}), total weed dry weight (0.46 and 1.38 g m^{-2}), higher WCE (94.22 and 93.89%) and lower WI (8.75%) and was on a par with two intercultivations at 20 and 40 DAS. Among herbicides tank mixtures, Imazethapyr + Quizalofop-p-ethyl (75 g + 37.50 g ha^{-1}) at their 75 per cent RD recorded significantly lower weed density (6.67 and 8.67 m^{-2}), total weed dry weight (1.90 and 2.73 g m^{-2}), higher WCE (77.75 and 85.79%) and lower WI (11.98%) over all other herbicide treatments (Table 2). It was on par with Imazethapyr + Propaquizafop ethyl at their 75 per cent RD and Imazethapyr + Fluazifop-p-butyl 75 per cent RD. This was mainly due to broad spectrum control of both grasses and BLWs with herbicide tank mixtures (Prachand *et al*., 2014) [5]. In tank mixture *i.e.*, Imazethapyr + Quizalofop-p-ethyl at 75 per cent RD, BLWs, were effectively controlled by Imazethapy and grasses were controlled by Quizalofop-p-ethyl. Same was the case with tank mixture Imazethapyr + Propaquizafop ethyl at their 75 per cent RD as this herbicide mixtures controlled BLWs and grassy weeds effectively.

Effect on weed control and phytotoxicity of soybean

Visual observations on weed control rating showed marked differences among the various weed management practices at 7, 14 and 21 days after herbicide spray (Table 3). Imazethapyr alone at 100 per cent RD did not show good weed control. While, Imazethapyr + Quizalofop-p-ethyl at their 75 per cent RD recorded good control of weeds (8.33 at 14 DAHS). This was due to the fact that Quizalofop-p-ethyl was effective in controlling grasses and Imazethapyr kills broad leaf weeds, thereby broad spectrum weed control can be. Hence tank mixture of these herbicides resulted in broad spectrum weed control. Similar findings were observed by Rao (2017).

The herbicides or herbicide tank mixtures used in the present studies did not cause any injury to the soybean crop at 14 and 21 DAHS. But at 7 DAHS, Imazethapyr alone at 100 per cent RD showed a slight stunting, injury or discolouration. Thereby indicating that all the herbicide mixtures or herbicide are safe and there was no phytotoxicity to soybean crop growth and yield (Table 4). Similar observations on phytotoxicity of Imazethapyr were observed earlier by Malligwad *et al.* (2016) [3].

Effect on yield and yield attributes of soybean

Imazethapyr + Quizalofop-p-ethyl (75% RD) recorded significantly higher plant height (52.53 cm), total dry weight per plant (27.30 g $plant^{-1}$), seed weight per plant (14.60 g $plant^{-1}$), number of pods per plant (46.33) and seed yield (2,554 kg ha^{-1}) and was on a par with Imazethapyr + Propaquizafop ethyl (75 + 75 g ha^{-1}) at their 75 per cent RD and Imazethapyr + Fluazifop-p-butyl at their (75 + 75 g ha^{-1}) at their 75 per cent RD (Table 4). This was attributed to reduced weed competition during the critical crop growth period which resulted in reduced weed dry weight and WI and also enabled the crop to utilize the available natural resources like moisture, nutrients, space and light to maximum extent by reducing the competition between the weeds and crop (Prachanda *et al.*, 2015) [5]. But, Imazethapyr alone (100 g ha^{-1} at 100% RD) recorded lower growth, yield attributes and seed yield compared to tank mixtures. This was mainly due to more weed infestation and there was no broad spectrum weed control with Imazethapyr alone during crop growth period (Sangeetha *et al.*, 2012) [6]. Some herbicides when used alone control a specific group of weeds.

Effect on economics of soybean

Imazethapyr + Quizalofop-p-ethyl at their 75 per cent RD recorded higher net returns (₹ 59,111 ha^{-1}) and B: C ratio (2.42) and was on a par with Imazethapyr + Propaquizafop ethyl 75 per cent RD and Imazethapyr + Fluazifop-p-butyl at 75 per cent RD (Table 5). Among all the treatments, RWMP recorded markedly highest net returns (₹ 62,111 ha^{-1}) and B: C ratio (2.47) and was on a par with two inter cultivations at 20 and 40 DAS, Imazethapyr + Quizalofop-p-ethyl at 75 per cent RD and weed free treatment. These results are in conformity with the findings of (Thakare *et al.*, 2015) [8]. The higher net returns and B: C ratio is due to the higher grain yield and haulm yield with good market price. This is mainly because of broad spectrum weed control in these treatments which resulted in enhanced seed yield and haulm yield and in turn resulted in higher gross returns and net returns. Similar findings were recorded by Deshmukh *et al.* (2014) [2].

Conclusion

Findings of the present investigation revealed that tank mix application of post emergent herbicide *viz.*, Imazethapyr +

Quizalofop-p-ethyl their (75 + 37.50 g ha^{-1} at their 75% RD) or Imazethapyr + Propaquizafop ethyl (75+ 75 g ha^{-1} at their 75% RD) or Imazethapyr + Fluazifop-p-butyl (75 + 75 g ha^{-1} at their 75% RD) recorded significantly higher weed control efficiency and grain yield. But tank mix application of post emergent herbicide *viz.*, Imazethapyr + Quizalofop-p-ethyl their (75 + 37.50 g ha^{-1} at their 75% RD) recorded significantly higher net returns and B: C as a result of broad spectrum weed control.

Table 1: Treatment details

Tr. No	Treatment details
T_1	Imazethapyr (100 g ha^{-1} at their 100% RD at 20-25 DAS)
T_2	Imazethapyr + Quizalofop-p-ethyl (75 + 37.50 g ha^{-1} at their 75% RD at 20-25 DAS)
T_3	Imazethapyr + Quizalofop-p-ethyl (50 + 25 g ha^{-1} at their 50% RD at 20-25 DAS)
T_4	Imazethapyr + Fluazifop-p-butyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)
T_5	Imazethapyr + Fluazifop-p-butyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)
T_6	Imazethapyr + Propaquizafop ethyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)
T_7	Imazethapyr + Propaquizafop ethyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)
T_8	Imazethapyr + Fenoxaprop-p- ethyl (75 + 67.5 g ha^{-1} at their 75% RD at 20-25 DAS)
T_9	Imazethapyr + Fenoxaprop-p-ethyl (50 + 45 g ha^{-1} at their 50% RD at 20-25 DAS)
T_{10}	Imazethapyr + Imazamox (pre-mix) 100 g of CP ha^{-1} at 20-25 DAS
T_{11}	RWMP-Recommended weed management practice (Pendimethalin 1kg ha^{-1} PE + 1 IC)
T_{12}	Two inter-cultivations at 20 and 40 DAS
T_{13}	Weed free
T_{14}	Weedy check

RD: Recommended dose, DAS – days after sowing, PE – pre emergent

Table 2: Effect of different weed management practices on various weed parameters in soybean at 60 DAS

Treatments	Total number of weeds per m^2		Total dry weight of weeds (g m^{-2})		WCE (%)		Weed index (%)
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	
T_1 : Imazethapyr (100 g ha^{-1} at their 100% RD at 20-25 DAS)	3.43 (11.33)	3.97 (15.33)	1.96 (3.36)	2.23 (4.50)	60.71	76.57	28.01
T_2 : Imazethapyr + Quizalofop-p-ethyl (75 + 37.50 g ha^{-1} at their 75% RD at 20-25 DAS)	2.67 (6.67)	3.02 (8.67)	1.54 (1.90)	1.79 (2.73)	77.75	85.79	11.98
T_3 : Imazethapyr + Quizalofop-p-ethyl (50 + 25 g ha^{-1} at their 50% RD at 20-25 DAS)	3.28 (10.33)	3.71 (13.33)	1.93 (3.23)	2.25 (4.56)	67.92	77.48	26.39
T_4 : Imazethapyr + Fluazifop-p-butyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)	2.91 (8.00)	3.18 (9.67)	1.68 (2.33)	1.89 (3.1)	72.69	83.79	18.72
T_5 : Imazethapyr + Fluazifop-p-butyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)	3.71 (13.33)	4.18 (17.00)	1.95 (3.33)	2.27 (4.67)	60.84	75.62	31.19
T_6 : Imazethapyr + Propaquizafop ethyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)	2.79 (7.33)	3.12 (9.33)	1.61 (2.10)	1.81 (2.80)	75.23	85.41	18.80
T_7 : Imazethapyr + Propaquizafop ethyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)	3.67 (13.00)	4.06 (16.00)	2.07 (3.8)	2.27 (4.67)	60.84	75.64	29.49
T_8 : Imazethapyr + Fenoxaprop-p- ethyl (75 + 67.5 g ha^{-1} at their 75% RD at 20-25 DAS)	3.23 (10.00)	4.10 (16.33)	1.83 (2.87)	1.97 (3.40)	66.06	82.29	25.59
T_9 : Imazethapyr + Fenoxaprop-p-ethyl (50 + 45 g ha^{-1} at their 50% RD at 20-25 DAS)	3.97 (15.33)	4.48 (19.67)	2.02 (3.60)	2.29 (4.80)	55.43	75.04	32.17
T_{10} : Imazethapyr + Imazamox (pre-mix) 100 g of CP ha^{-1} at 20-25 DAS	3.53 (12.00)	4.14 (16.67)	1.95 (3.33)	2.22 (4.43)	57.57	76.83	32.94
T_{11} : RWMP-Recommended weed management practice (Pendimethalin 1kg ha^{-1} PE + 1 IC)	1.87 (2.33)	2.27 (4.00)	0.97 (0.47)	1.37 (1.38)	94.22	93.89	8.75
T_{12} : Two inter-cultivations at 20 and 40 DAS	1.67 (3.00)	2.11 (4.67)	1.10 (0.71)	1.29 (1.67)	91.54	92.79	9.12
T_{13} : Weed free	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	100.00	100.00	0.00
T_{14} : Weedy check	7.19 (51.33)	8.30 (70.67)	3.00 (8.56)	4.43 (19.20)	0.00	0.00	53.73
S. Em. ±	0.11	0.14	0.05	0.08	2.56	2.46	1.57
C.D. at 5%	0.34	0.41	0.14	0.24	7.45	7.16	4.58

DAS - days after sowing, PE - pre emergent, IC- inter-cultivation, CP- commercial product, RD- recommended dose. In weed free check first weeding was done at 18 DAS.

Table 3: Weed control rating and Phytotoxicity rating as influenced by weed management practices in soybean

Treatments	Weed control rating (0-1 0)			Phytotoxicity rating (0-1 0)		
	7 DAHS	14 DAHS	21 DAHS	7 DAHS	14 DAHS	2 DAHS
T_1 : Imazethapyr (100 g ha^{-1} at their 100% RD at 20-25 DAS)	1.67	6.83	6.67	1.00	0	0
T_2 : Imazethapyr + Quizalofop-p-ethyl (75 + 37.50 g ha^{-1} at their 75% RD at 20-25 DAS)	4.67	8.33	7.67	0.75	0	0
T_3 : Imazethapyr + Quizalofop-p-ethyl (50 + 25 g ha^{-1} at their 50% RD at 20-25 DAS)	2.67	7.33	6.33	0.5	0	0
T_4 : Imazethapyr + Fluazifop-p-butyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)	4.33	7.83	7.33	1	0	0
T_5 : Imazethapyr + Fluazifop-p-butyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)	3.67	7.33	6.67	0.5	0	0
T_6 : Imazethapyr + Propaquizafop ethyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)	4.50	8.33	7.53	0.75	0	0
T_7 : Imazethapyr + Propaquizafop ethyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)	3.33	7.52	6.77	0	0	0
T_8 : Imazethapyr + Fenoxaprop-p- ethyl (75 + 67.5 g ha^{-1} at their 75% RD at 20-25 DAS)	3.33	7.53	7.33	0	0	0
T_9 : Imazethapyr + Fenoxaprop-p-ethyl (50 + 45 g ha^{-1} at their 50% RD at 20-25 DAS)	2.00	6.77	6.83	0	0	0
T_{10} : Imazethapyr + Imazamox (pre-mix) 100 g of CP ha^{-1} at 20-25 DAS	3.33	6.53	6.17	0.5	0	0
T_{11} : RWMP- Recommended weed management practice (Pendimethalin 1kg ha^{-1} PE + 1 IC)	9.57	9.17	8.33	0	0	0
T_{12} : Two inter-cultivations at 20 and 40 DAS	9.23	8.77	9.17	-	-	-
T_{13} : Weed free	10.00	10.00	10.00	-	-	-

T_{14} : Weedy check	0.00	0.00	0.00	-	-	-
S. Em. ±	0.24	0.26	0.22			
C.D. at 5%	0.70	0.77	0.66			

DAS - days after sowing, PE - pre emergent, IC- inter-cultivation, CP- commercial product, RD- recommended dose. In weed free check first weeding was done at 18 DAS.

Table 4: Effect of different weed management practices on various growth (60 DAS), yield attributes, yield and economics of soybean

Treatments	Plant height (cm)	Total dry weight (g plant^{-1})	Number of pods per plant	Seed weight (g plant^{-1})	Grain yield (kg ha^{-1})	Net returns (`ha^{-1})	B: C ratio
T_1 : Imazethapyr (100 g ha^{-1} at their 100% RD at 20-25 DAS)	47.40	49.07	41.33	13.30	2,095	42,246	2.04
T_2 : Imazethapyr + Quizalofop-p-ethyl (75 + 37.50 g ha^{-1} at their 75% RD at 20-25 DAS)	52.53	54.00	46.33	14.60	2,554	59,111	2.42
T_3 : Imazethapyr + Quizalofop-p-ethyl (50 + 25 g ha^{-1} at their 50% RD at 20-25 DAS)	47.57	49.20	42.00	13.37	2,137	44,256	2.10
T_4 : Imazethapyr + Fluazifop-p-butyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)	48.83	51.33	44.27	14.40	2,357	50,482	2.18
T_5 : Imazethapyr + Fluazifop-p-butyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)	47.83	48.97	41.87	13.40	1,996	38,135	1.93
T_6 : Imazethapyr + Propaquizafop ethyl (75 + 75 g ha^{-1} at their 75% RD at 20-25 DAS)	51.17	52.80	45.60	14.50	2,356	50,791	2.20
T_7 : Imazethapyr + Propaquizafop ethyl (50 + 50 g ha^{-1} at their 50% RD at 20-25 DAS)	47.93	49.13	41.93	13.43	2,046	40,185	1.99
T_8 : Imazethapyr + Fenoxaprop-p- ethyl (75 + 67.5 g ha^{-1} at their 75% RD at 20-25 DAS)	49.03	50.13	42.33	13.90	2,157	43,708	2.05
T_9 : Imazethapyr + Fenoxaprop-p-ethyl (50 + 45 g ha^{-1} at their 50% RD at 20-25 DAS)	46.13	48.70	41.33	13.17	1,971	37,629	1.93
T_{10} : Imazethapyr + Imazamox (pre-mix) 100 g of CP ha^{-1} at 20-25 DAS	47.87	48.07	41.07	13.20	1,946	35,688	1.87
T_{11} : RWMP-Recommended weed management practice (Pendimethalin 1kg ha^{-1} PE + 1 IC)	54.03	54.47	46.83	14.73	2,652	62,111	2.47
T_{12} : Two inter-cultivations at 20 and 40 DAS	53.53	54.33	46.47	14.67	2,639	61,997	2.50
T_{13} : Weed free	55.10	55.37	47.60	15.10	2,906	58,492	2.04
T_{14} : Weedy check	42.67	47.00	23.33	11.83	1,345	16,652	1.44
S. Em ±	1.50	1.48	1.35	0.43	92	3556	0.08
C.D. at 5%	4.38	4.30	3.93	1.25	267	10338	0.25

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